ELECTROMYOGRAPHICAL DIFFERENCES IN THE MUSCULAR ACTIVITY OF THE LUMBOPELVIS AND HIP REGION BETWEEN MID- AND HIGH-SECTION TAEKWONDO TURNING KICKS

by

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2. Abstract

This study aimed to compare the electromyographical (EMG) levels, timings and patterns of selected lumbopelvis and hip muscles between mid- and high-section Taekwondo turning kicks. Thirteen healthy elite (internationally competitive) Taekwondo athletes participated (age: 21.00 ± 3.00 years; mass: 72.89 ± 8.64 kg; stature: 1.79 ± 0.05 m). Subgroups included an ‘injury’ group ($n = 6$) with lumbopelvic region injury history, and a ‘no injury’ group ($n = 7$). Participants randomly performed 8 maximal dominant back leg mid- and high-section turning kicks. Surface EMG of the kicking and support leg external obliques (EO), gluteus maximus (GM), adductor longus (AL), and biceps femoris (BF) were analysed. Data were normalised to isometric maximum voluntary contractions (MVC). Paired-sampled t-tests were adopted for statistical analyses ($p < 0.05$). Overall, mid-section kicks resulted in significantly greater kicking leg mean GM and AL, peak GM EMG levels ($p < 0.05$), and shorter kick durations ($p < 0.01$) than high-section turning kicks. Times to peak EMG level results were inconclusive. Within the ‘injury’ subgroup, significantly greater peak loading phase support leg BF activity was observed during mid- compared to high-section turning kicks ($p < 0.05$). Effect sizes were large ($r > 0.80$). In conclusion, greater EMG activity was produced during mid- compared to high-section turning kicks, perhaps because of faster kicking velocities. In the ‘injury’ subgroup the support leg hamstrings and groin appeared vulnerable to injury due to high loading phase mid-section BF activity and / or kicking phase high-section BF activity, and poor coactivation of the GM and AL respectively. However, high inter-participant CV (> 0.80) suggests poor repeatability. Further research is needed to provide more valid conclusions.

3. Declaration

No portion of the work referred to in this Research Project has been submitted in support of an application for another degree or qualification of this, or any other University or institute of learning.

The project was supervised by a member of academic staff, but is essentially the work of the author.

Copyright in text of this Research Project rests with the author. The ownership of any intellectual property rights which may be described in this thesis is vested in the University of Chester and may not be made available to any third parties without the written permission of the University.

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Chapter 1

7.1. Introduction

Taekwondo is an ancient Korean martial art. Today, it is a global sport continually gaining in international reputation, enhanced by its inclusion into the Olympics since the 2000 Sydney Olympic Games. Governed by the World Taekwondo Federation (WTF), WTF Taekwondo now boasts over 200 member nations and 80 million practitioners worldwide (World Taekwondo Federation News, 2012).

It is characterised by its emphasis on fast, dynamic, successive kicks performed to an opponent's torso (mid-section) or head (high-section) to score points (Harun & Xiong, 2010; Lystad, Pollard, & Graham, 2009). Elite level Taekwondo athletes require great sport-specific technical prowess and tactical know-how, but also excellent stamina, speed, strength, power, flexibility, balance and coordination in order to execute such actions efficiently and effectively (Lystad et al., 2009).

The full-contact nature of WTF Taekwondo results in high competition injury incidence rates (Beis, Pieter, & Abatzides, 2007; Kazemi et al., 2009; Kazemi & Pieter, 2004; Lystad et al., 2009; Pieter, Fife, & O-Sullivan, 2012; Zetaruk, Violan, Zurakowski, & Micheli, 2005; Ziaee, Rahmani, & Rostami, 2010). In a multi-sport meta-analysis by Lystad et al. (2009) Taekwondo had the highest injury incidence rate (79.3 per 1000 athlete-exposures (A-E)), distantly followed by American football (35.9 per 1000 A-E). The lower extremities have been shown to be of greatest risk (Pieter et al., 2012), particularly in comparison to other martial arts (Zetaruk et al., 2005) (Table 1). Consequently, Taekwondo has incurred a number of competition safety regulations attempting to reduce these figures (Burke et al., 2003). Injury attainment from excessive training has received limited attention. However, Feehan and Waller (1995) found high pre-competition incidence rates for lower limb soft tissue injuries.

Table 1 Comparison of five martial arts in terms of injury rates by region of the body (Zetaruk et al., 2005).

Style	**No.**[1]	**Upper Extremity**	**Lower Extremity**	**Groin**	**Trunk**	**Head / neck**
Karate	114	16.7	22.8	0.9	14.9	9.6
TKD[2]	49	40.8	57.1	18.4	24.5	30.6
Aikido	47	42.6	34.0	6.4	25.5	31.9
Kung Fu	39	20.5	35.9	5.1	12.8	10.3
Tai Chi	14	7.1	7.1	0.0	7.1	7.1
Total	263	25.9	32.3	5.7	17.9	17.5

Notes:

[1] Number of participants

[2] Taekwondo

Understanding of the mechanisms of these injuries in martial arts is limited. Shan (2005) showed Taekwondo practitioners to have high lower extremity injury risk as a result of great muscle lengthening speeds and hip range of motion (ROM). The high training exposure of elite Taekwondo could increase such risks as athletes regularly perform prolonged repetitive kicking drills. Tissue damage is most likely under fatiguing conditions, when overloading through extreme postures acts as a trigger (Shan, 2005). The adductor magnus, gracillis, and semimembranosus were at greatest risk because, when lengthened, they are often unable to withstand the huge inertial forces produced (Shan, 2005).

In dancing, studies have focused on lumbopelvic injuries, generally caused by excessive lumbar spine extension as a result of lower limb hyperextension (Dolan & Adams, 1993; Gelabet, 1986; Nicholls, 2004; Vad et al., 2004; Wightman, 2004). This causes intervertebral disc compression if posterior pelvis tilt is not maintained through a strong core (Gelabert, 1986; Nicholls, 2004; Wightman, 2004) and large available ROM (Dolan & Adams, 1993; Vad et al., 2004). Lumbopelvic disorders can also cause related groin and hamstring pain / injury (Reiman, Weisbach, & Glynn, 2009; Wallden & Walters, 2005). Therefore, Taekwondo athletes require good lower extremity and trunk flexibility coupled with strength at these ranges to prevent related injuries.

In 2009 the WTF General Assembly approved amendments to the WTF Competition Rules with the premise of making Taekwondo more dynamic (Virdi et al., 2009; World Taekwondo Federation, 2012). Amongst the changes was the introduction of a points differentiation based on kick target and complexity, e.g. more points available for valid high-section kicks. This emphasis on high-section kicks has influenced competition and training strategy. Thus, it could have incrementally affected lumbopelvic related injury rates due to the greater ROM required of these kicks. Kim, Kim, Lee, Han, and Kwon (2010) demonstrated that posterior pelvis tilt range for mid-section turning kicks (roundhouse kicks) was 55.6 ± 6.3 º compared to 65.2 ± 9.5 º for high-section kicks, likewise for left pelvis tilt (mid: 11.2 ± 6.2 º, high: 23.8 ± 9.0 º), left pelvis rotation (mid: 118.5 ± 26.4 º, high: 134.8 ± 26.14 º), trunk extension (mid: 18.9 ± 7.3 º, high: 22.2 ± 7.0 º), and hip abduction (mid: 20.7 ± 9.5 º, high: 36.2 ± 7.3 º).

In competition the turning kick is the most utilised kick, accounting for 72.7 % of kicks performed (Luk, Hong, & Chu, 2001). Biomechanically, it is described as a throw-like movement starting with hip flexion; the leg travelling in an arc towards the front with the knee in a chambered position, leading to knee extension; a snapping movement making contact with the target with the tibia or metatarsal part of the extended foot (Falco et al., 2009; Kim, Kim, & Im, 2011; Lees, 2002) (Figure 1). It is invaluable in competition as it is fast, powerful and effective to different targets (Estevan, Falco, Alvarez, Mugarra, & Iradi, 2009; Kim et al., 2011; Kim et al., 2010; Kim, Yenuga, & Kwon, 2008; Li, Yan, Zeng, & Wang, 2005; Wąsik, 2010). Of these turning kick types, Hong, Kam, and Jim (2000) reported mid-section kicks to be faster (0.80 ± 0.09 s) than high-section kicks (0.90 ± 0.09 s).

Figure 1 The back-leg Taekwondo turning kick (adapted from Physical Arts, 2000).

Limited biomechanical research exists on martial arts compared to other sports. Within existing research there great emphasis on the principle of proximal-to-distal sequencing to produce a greater distal-end / foot velocity (Pearson, 1997; Sørenson, Zacho, Simonsen, Dyhre-Poulsen, & Klausen; 1996), some emphasis on the stretch shortening cycle (SSC) as a means of enhancing this summation of speed (Harun & Xiong, 2010), and finally, some emphasis on the ROM differences between mid and high-section kicks (Kim et al. 2010).

One major limitation of existing martial arts research is the lack of electromyographical (EMG) analyses. EMG has three main applications: to indicate muscle activation initiation, to understand force production, and as fatigue index (De Luca, 1997). Thus, it is supportive in understanding, enhancing performance, and preventing injury during any activity. The majority of kicking EMG research comes from soccer. The topics of muscle activity patterns (Orchard, Walt, McIntosch, & Garlick, 1999), accuracy (Katis et al., 2013; Scurr, Abbott, & Ball, 2011) and injury (Morrissey et al., 2012; Serner et al., 2013) have been investigated, however the kicks studied differ biomechanically from martial arts kicks.

In martial arts, Peng, Ji, Li, and Dong (2012) found the greatest muscle activity from the tensor fascia latae (859.00 uV), semimembranosus tendon (303.00 uV), gluteus maximus (285.00 uV), and medial gastrocnemius (285.00 uV) during the Taekwondo chop kick. However, no EMG normalisation procedures were undertaken, meaning that direct inter-muscular comparisons cannot be made due to muscle anatomical differences. Only one EMG study was found comparing mid- and high-section turning kicks. Significantly greater EMG levels were reported of the sartorius , tensor fascia latae and vastus lateralis when performing high- compared to mid-section turning kicks ($p < 0.05$) (Luk & Hong, 2000). This may suggest greater strain of these muscles as a result of the greater ROM required of high-section kicks, however implications were not reported. Additionally, the level (7.11 ± 2.51 years, 2.57 ± 1.74 hours / week), number of participants ($n = 14$), and number of trials ($n = 3$) in this study are questionable. Further research is warranted on the EMG levels of muscles acting over the lumbopelvis and hips during kicks performed at varying heights.

Acquiring such data could be beneficial to coaches, physiotherapists, and athletes. It could provide key EMG level and timing differences which may aid to explain the high lumbopelvis region related injury rates, particularly of the groin and hamstrings, in elite Taekwondo. Strength and conditioning coaches (S & C) could also benefit from an increased understanding of key differences between mid- and high-section turning kicks in injury prevention and, potentially, performance enhancement.

The purpose of this study was to compare the kick duration, and EMG levels, timings and patterns of selected muscles of the lumbopelvis and hip region between mid- and high-section Taekwondo turning kicks. Based on the increased ROM required in high-section kicking (Kim et al., 2010; Shan, 2005) and the greater EMG levels reported by Luk and Hong (2000) when performing high-section turning kicks, the hypotheses were three-fold. It was hypothesised that high-section kicks: 1) would elicit significantly greater peak and mean EMG levels; 2) their peak EMG levels would occur later; and 3) their kick duration would be significantly longer, compared to mid-section turning kicks.

Chapter 2

8. Method

8.1. Participants

Following ethical approval from the Faculty of Research Ethics Committee (3rd June 2013 / reference number: 816/13/YR/SES) (Appendix 1) at the University of Chester, raw EMG data collected by an elite Taekwondo organisation were analysed retrospectively. Data were available for a sample of 10 male and 3 female healthy elite (internationally competitive) Taekwondo athletes. Subgroups included an 'injury' and a 'no injury' group. Details of all groups are in Table 2 and Appendix 2. As the hypotheses were mainly one-tailed and based on the sample size of 13 (n), a significance level of 0.05 (α), a power ($1 - \beta$) of 0.8, a medium effect size (g) of 0.73 was determined (Cohen, 1988). As no research on kicking found reported effect size, a medium to large effect size was deemed adequate.

8.2. Design

The investigation was a one group repeated-measures experimental design involving 3 independent groups between which no statistical comparisons were made. The dependent variables were the peak and mean normalised EMG activation levels (percentage of maximum voluntary contraction (%MVC)) and timings to each comparable observable peak for the kicking and support leg external obliques (EO), gluteus maximus (GM), adductor longus (AL) and biceps femoris (BF). Kick duration (movement initiation to impact) and patterns of activation were also analysed. The independent variables were, 1) the height of the kicking target (mid- or high-section) which was individualised for each participant, and 2) the same comparisons were made within 'injury' group and 'no injury' group independently.

Table 2 Grouping criteria and anthropometrics (mean ± standard deviation).

Group	Criteria	Sex[1]	Number	Age (yrs)	Mass (kg)	Stature (m)
All	Healthy elite Taekwondo player.	M	10	21.40 ± 3.50	73.82 ± 8.82	1.79 ± 0.06
		F	3	20.33 ± 0.58	69.80 ± 1.76	1.76 ± 0.05
Injury	Healthy elite Taekwondo player who had attained hamstring, groin and / or gluteal injury within 8 months prior to data collection.	M	5	21.43 ± 3.78	73.34 ± 7.95	1.81 ± 0.03
		F	1	20.00 ± 0.00	59.60 ± 0.00	1.71 ± 0.00
No Injury	Healthy elite Taekwondo player who had not attained any hamstring, groin and / or gluteal injury within 8 months prior to data collection.	M	5	23.2 ± 3.56	72.16 ± 9.65	1.78 ± 0.07
		F	2	20.5 ± 0.71	74.8 ± 1.13	1.79 ± 0.01

Notes:

[1] M = Male, F = Female

Based on the actions performed by these muscles (Table 3), following Hong et al. (2000), Kovacich (2005), Luk and Hong (2000), Sørenson et al. (1996), and recommendations from the sport's physiotherapists, the muscle activity of the kicking and support leg EO, GM, AL and BF were measured by means of 8 surface electrodes (inter-electrode distance = 2 cm) (Noraxon USA Inc., Scottsdale, Arizona) (Figure 2). A reference electrode was placed on the anterior superior iliac spine (ASIS) on the support leg side (Figure 3).

Table 3 Muscles of interest and their actions during the kicking action, including the external obliques (EO), gluteus maximus (GM), adductor longus (AL) and biceps femoris (BF).

Muscle	**Actions**
EO	Collateral rotation of the torso to position and stabilise the body (Calais-Germain, 1999).
GM	Posteriorly tilt and rotate the pelvis to maintain posture and stability (Calais-Germain, 1999).
AL	Adducts and flexes the hip to bring the kicking leg across the target whilst maintaining and stabilising the hip in its abducted position (Calais-Germain, 1999).
BF	Act to decelerate the kicking leg after impact through eccentric contraction and assists to control the kick (Dunn & Putnam, 1987; Lees, Asai, Anderson, Nunome, & Sterzing, 2010; Lees & Nolan, 1998; Katis & Kellis; 2010).

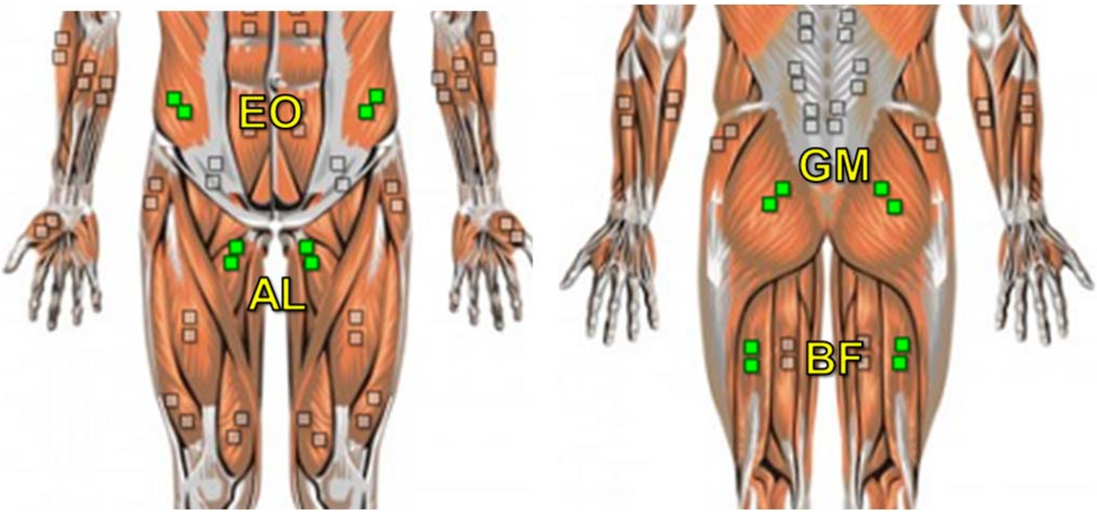

Figure 2 Surface electrode placement sites for the external obliques (EO), gluteus maximus (GM), adductor longus (AL) and biceps femoris (BF).

Figure 3 Reference electrode placement on the anterior superior iliac spine (ASIS).

8.3. Procedures

Each participant attended one 1.5 hour testing session at their training facility as part of their organisation's physiotherapy screening. Shorts were necessary for electrode placement. Prior to EMG testing, anthropometric measures were taken, along with weight division, dominant kicking leg and lower extremity injury history.

Electrodes (Noraxon USA Inc., Scottsdale, Arizona) were placed following the conventional SENIAM recommendations to avoid dynamic EMG limitations (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). Prior to placement, skin was shaved and treated with alcohol to reduce skin impedance and improve skin-electrode contact. Electrodes were placed on the midline of the muscle belly and aligned with the underlying muscle striation. All preamps and wires were taped down to reduced movement artefacts. Manual muscle testing was performed to ensure accurate electrode placement and appropriate related EMG signals regarding each muscle (De Luca, 1997).

Following electrode placement, participants completed a 10 minute standardised warm-up consisting of a 2 minute pulse-raiser, a 5 minute stretch routine, and 3 minutes of paddle-pad work. MVCs for each muscle were then completed following trunk and hip MVC procedure recommendations (Konrad, 2005). Participants were verbally encouraged to produce and maintain a maximal contraction for 3 to 5 s before relaxing. Participants then stood in their fighting stance, dominant leg behind, at comfortable distance from the target and performed 3 dominant back leg turning kicks at both target heights for task familiarisation. For high-section kicks the target was positioned so that the top of paddle-pad was level with each participant's stature and for mid-section kicks so that the bottom of the paddle-pad was level with the umbilicus.

Each participant then randomly performed 8 successful maximal effort dominant back leg turning kicks at both target heights. Inaccurate kicks were disregarded and participants continued until 8 successful kicks were completed. When possible, the same high performance coach held the target. Target height accuracy was confirmed via visual inspection using a two-dimensional camera. There was a 30 s inter-trial rest period to reduce practice and fatigue effects.

For data analyses the movement was separated into the 3 phases (Figure 4). The movement was recorded using a two-dimensional camera positioned perpendicular to the frontal plane and synchronised to the EMG data using MyoResearch XP Master (Noraxon USA Inc, Scottsdale, Arizona) in which data were also processed (Appendix 3A and 3B). Prior to testing, raw baseline EMG signals were checked (< 5 uV) to ensure accurate electrode placement (Burden, 2008). Raw signals were sampled at 1500 Hz; amplified; Butterworth band-pass filtered (10 - 300 Hz) following previous research, a visual inspection and a spectrum report (Luk & Hong, 2000); and processed using a root mean squared algorithm with a 50 m/s moving rectangular window (Burden, 2008). For standardisation purposes, data were normalised to a MVC for each muscle (Appendix 3C).

Figure 4 The three phases of the back-leg Taekwondo turning kick defined by four key events (adapted from Physical Arts, 2000).

8.4. Statistical analyses

Statistical analyses were performed using SPSS 20.0 for Windows (SPSS Inc., Chicago, IL, USA) (Appendix 4A). For within-group comparisons of mid- and high-section turning kicks; kick duration, mean and peak EMG levels and timings were reported as a mean value across all trials within and then across participants. Each comparable peak observed within the data was used for statistical analyses. The inter-participant repeatability of these data points was tested using the coefficient of variation (CV) (Appendix 4B).

A Shapiro-Wilk statistic and test of homogeneity found the majority of data to be normally distributed ($p > 0.05$) and so normal distribution was assumed for all data sets (Appendix 4A). Consequently, kick durations, mean and peak EMG levels and timings were compared between mid- and high-section turning kicks using parametric paired sampled *t*-tests with a significance level of $p < 0.05$. Comparisons between mid- and high-section turning kicks were also made within the ‘injury’ and ‘no injury’ groups using paired sampled *t*-tests with a significance level of $p < 0.05$. Effect size was determined for each comparison following Cohen (1988), whereby values greater than 0.8, 0.5 and 0.2 denote large, medium and small effect sizes respectively (Appendix 4B). The Bonferroni correction for multiple-comparison was not performed because of lack of significant differences found at $p < 0.01$ and the large effect sizes observed (Nakagawa, 2004). Gelman, Hill, and Yajima (2012) argued that it is rarely possible for the null hypothesis to be strictly true. By not making these adjustments, interpretation errors could be reduced when the data are not random numbers but actual observations (Rothman, 1990).

Chapter 3

9. Results

Eight mid- and high-section turning kicks were collected per participant (Appendix 3 & 5). However, following visual inspections of the data, one high-section trial for one male ‘no injury’ participant was disregarded for all muscles. Additionally, one mid-section support leg EO trial for one male ‘no injury’ participant, and three high-section kicking leg EO trials for one male ‘injury’ participant were disregarded.

9.1. Kick duration (movement initiation to impact) (Appendix 4 & 5)

Table 4 demonstrates that regardless of injury history status, kick duration was significantly longer for high- compared to mid-section turning kicks (t = -3.88; d.f. 12; p < 0.01; large effect size). Therefore, null hypothesis 3 was rejected. The coefficient of variation (CV) for the whole group was 11.38 %.

Table 4 Mean mid- and high-section kick durations (± standard deviation) including coefficient of variation (CV) and effect size values for all groups (* p < 0.05, ** p < 0.01).

	Mid-section kick duration		**High-section kick duration**		
Group	**Mean ± SD (s)**	**CV (%)**	**Mean ± SD (s)**	**CV (%)**	**Effect size (*r*)**
All **	0.48 ± 0.06	11.86	0.50 ± 0.06	11.38	0.93
Injury **	0.46 ± 0.06	13.90	0.48 ± 0.07	14.67	0.97
No Injury *	0.50 ± 0.05	9.59	0.52 ± 0.04	8.10	0.87

<u>9.2. Mean EMG levels (Appendix 4 & 5)</u>

Mid-section kicks produced greater overall mean EMG levels than high-section turning kicks (Figure 5). This difference was significant for the kicking leg GM (t = 1.86; d.f. 12; p < 0.05; large effect size) and AL (t = 4.27; d.f. 12; p < 0.01; large effect size). Therefore, null hypothesis 1 was accepted. The support leg AL produced the greatest mean activity regardless of target height. Inter-participant CV values ranged from 25.70 % and 89.62 %.

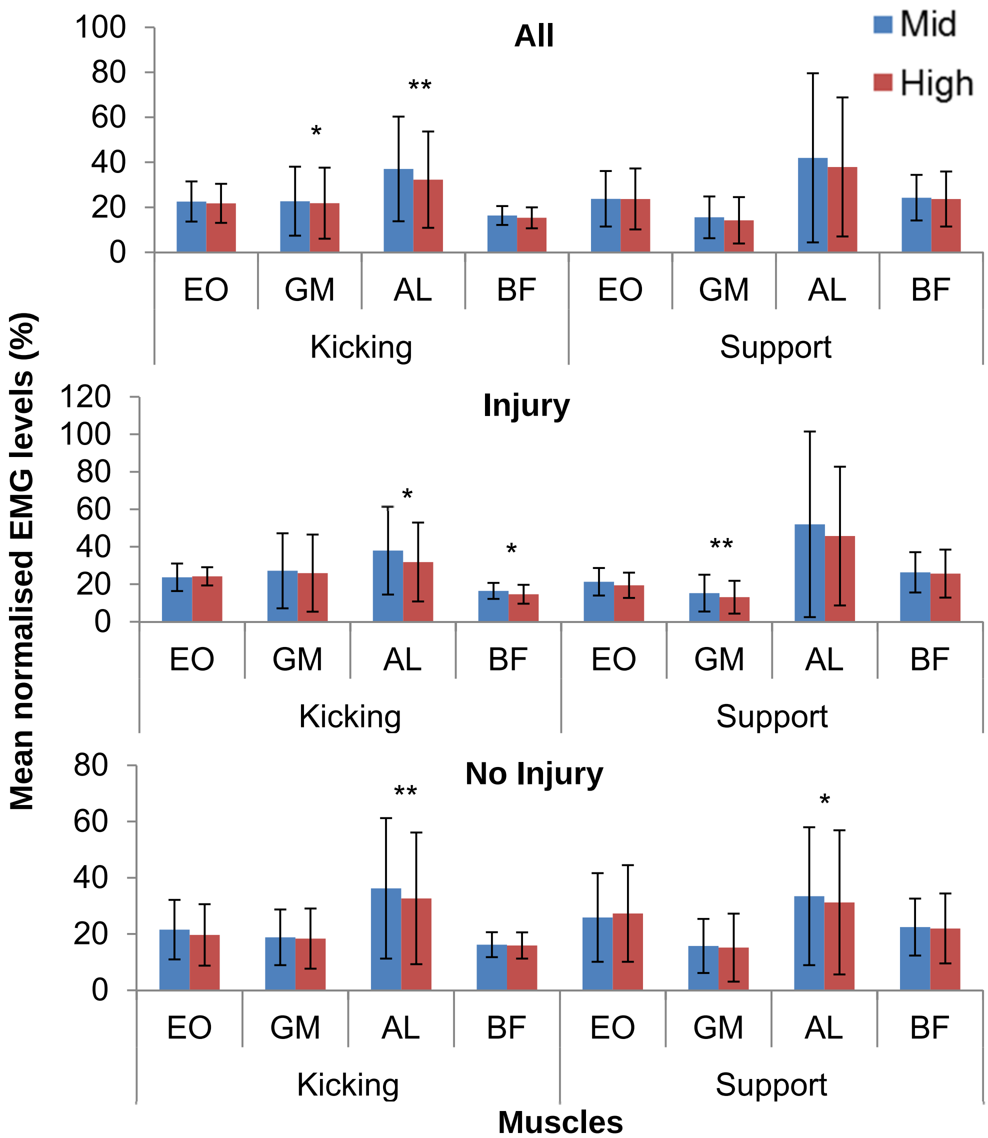

Figure 5 Comparison of mean (± standard deviation) EMG levels between mid- and high-section turning kicks for all groups (* p < 0.05, ** p < 0.01).

Within the ‘injury’ subgroup mid-section kicks produced significantly greater kicking leg AL (t = 1.99; d.f. 5; $p < 0.05$; large effect size), BF (t = 2.34; d.f. 5; $p < 0.05$; large effect size) and support leg GM (t = 3.43; d.f. 5; $p < 0.01$; large effect size) mean EMG levels than high-section turning kicks. Within the ‘no injury’ group mid-section kicks produced significantly greater kicking leg AL (t = 4.52; d.f. 6; $p < 0.01$; large effect size) and support leg AL (t = 2.58; d.f. 6; $p < 0.05$; large effect size) mean EMG levels than high-section turning kicks. Inter-participant CV values ranged from 20.16 % to 95.35 % in the ‘injury’ subgroup, and 27.48 % to 82.10 % in the ‘no injury’ subgroup.

9.3. Peak EMG levels (Appendix 4 & 5)

9.3.1. Whole group peak EMG levels

The greatest peak EMG levels were observed within the loading phase for the kicking and support leg EO, GM and BF (Figure 6). The support leg AL and BF and the kicking leg AL produced the greatest EMG levels within the kicking phase. Paired sampled t-tests showed that kicking leg GM EMG levels were significantly greater when kicking mid-section (42.14 ± 34.98 %MVC at 48.85 ± 13.22 %movement) compared to high-section turning kicks (38.08 ± 32.36 %MVC at 47.77 ± 13.48 %movement) (t = 2.24; d.f. 12; $p < 0.05$; large effect size) in the kicking phase (Figure 7). Likewise, mid-section turning kicks exhibited significantly greater peak kicking leg BF EMG levels (13.61 ± 9.37 %MVC at 76.77 ± 10.29 %movement) than high-section turning kicks (10.58 ± 6.18 %MVC at 81.62 ± 7.84 %movement) (t = 2.12; d.f. 12 $p < 0.05$; large effect size), thus accepting null hypothesis 1. Inter-participant CV values ranged from 23.86 % to 84.99 %.

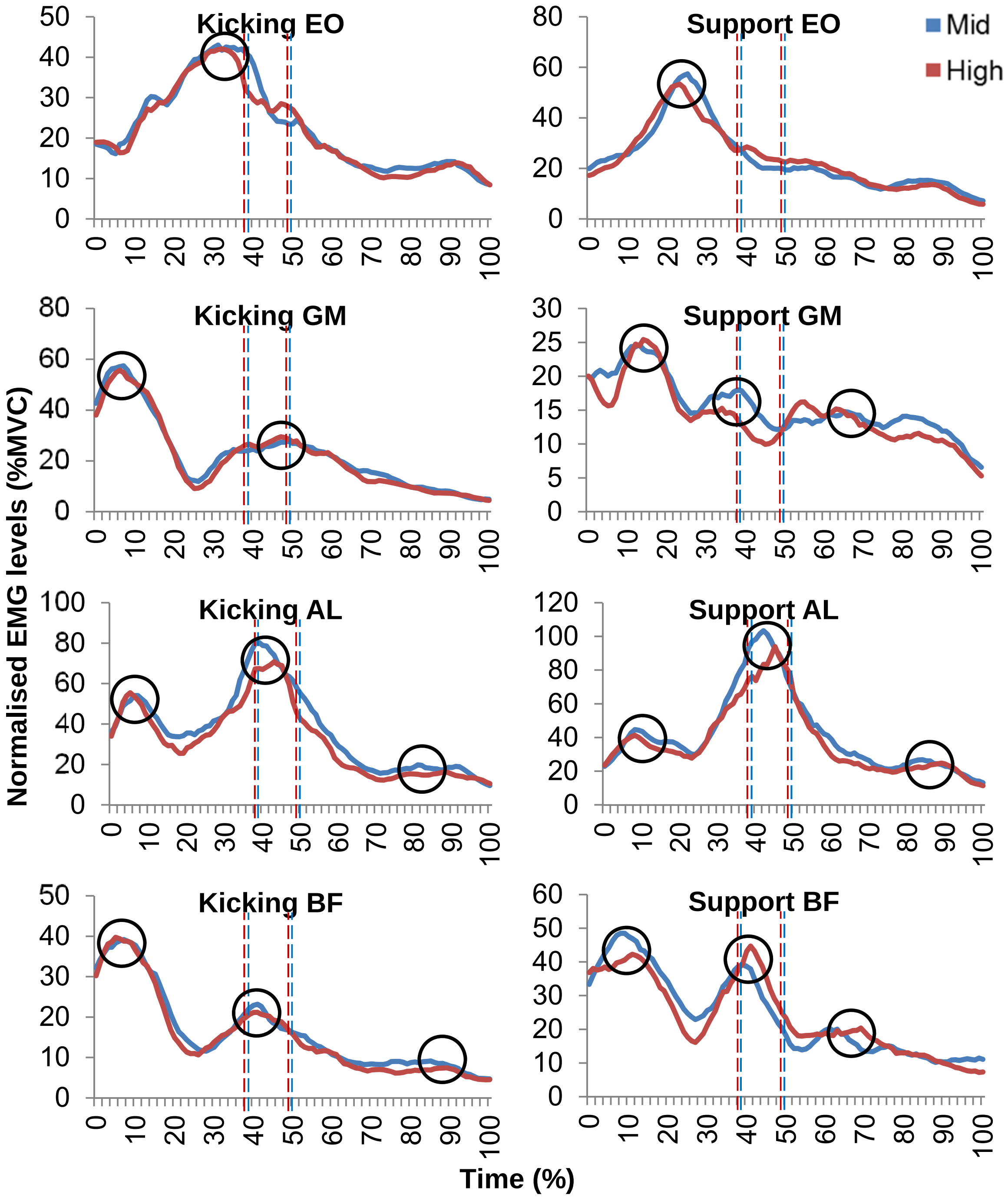

Figure 6 Patterns of activation of the kicking and support leg external obliques (EO), gluteus maximus (GM), adductor longus (AL) and biceps femoris (BF) EMG levels between mid- and high-section turning kicks and their comparable peaks for the whole group. The left vertical line demonstrates the point of most acute knee angle, and the right line, the point of impact.

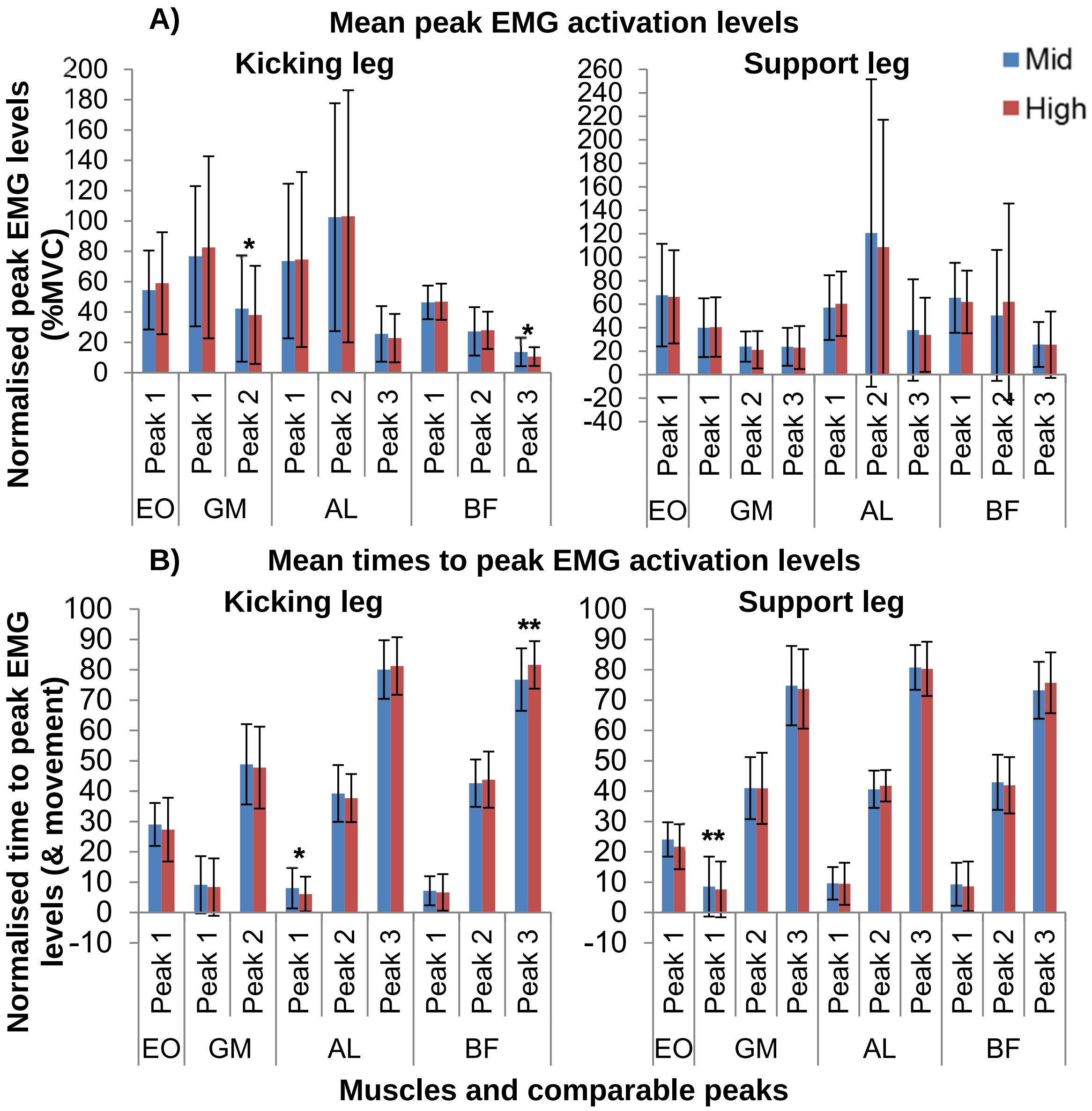

Figure 7 Mean peak EMG levels (A) and timings (B) in relation to Figure 6 for the external obliques (EO), gluteus maximus (GM), adductor longus (AL) and biceps femoris (BF) EMG levels between mid- and high-section turning kicks for the whole group (* $p < 0.05$, ** $p < 0.01$).

Figure 7B shows that high-section kicking leg AL ($t = 1.8$; d.f. 12; $p < 0.05$; large effect size) and support GM ($t = 2.52$; d.f. 12; $p < 0.01$; large effect size) levels peaked significantly faster than mid-section kicks in the loading phase. Therefore, null hypothesis 2 could be accepted. However, for the third peak, mid-section kicks exhibited greater kicking leg BF activity significantly sooner (13.61 ± 9.37 %MVC at 76.77 ± 10.29 %movement) than high-section turning kicks (10.58 ± 6.18 %MVC at 81.62 ± 7.84 %movement) (t = -3.52; d.f. 12 $p < 0.01$; large effect size). Inter-participant CVs were high, ranging from 9.13% to 120.77 %.

9.3.2. 'Injury' subgroup peak EMG levels

Within the 'injury' subgroup, paired sampled *t*-tests showed significantly greater peak EMG activity for mid- compared to high-section turning kicks for the kicking leg GM (t = 2.41; d.f. 5; $p < 0.05$; large effect size) in kicking phase, the support leg EO (t = 2.73; d.f. 5; $p < 0.05$; large effect size) and BF (t = 2.43; d.f. 5; $p < 0.05$; large effect size) in loading phase, and support leg BF (t = 2.08; d.f. 5; $p < 0.05$; large effect size) in recovery phase (Figure 9A). Therefore, null hypothesis 1 was accepted. Inter-participant CV values for were high, ranging from 20.25 % to 146.37 %.

Figure 9B shows the final comparable peak for kicking leg BF took significantly longer to peak during high- (11.76 ± 7.53 %MVC at 83.33 ± 4.63 %movement) compared to mid-section turning kicks (13.09 ± 8.97 %MVC at 79.33 ± 7.17 %movement) (t = -2.03 ; d.f. 5; $p < 0.05$; large effect size), thus rejecting null hypothesis 2. However, in the loading phase mid-section support leg GM activity peaked later than in high-section turning kicks (t = 2.24; d.f. 5; $p < 0.05$; large effect size), supporting null hypothesis 2. Inter-participant CV values were high, ranging from 11.17 % to 150.69 %.

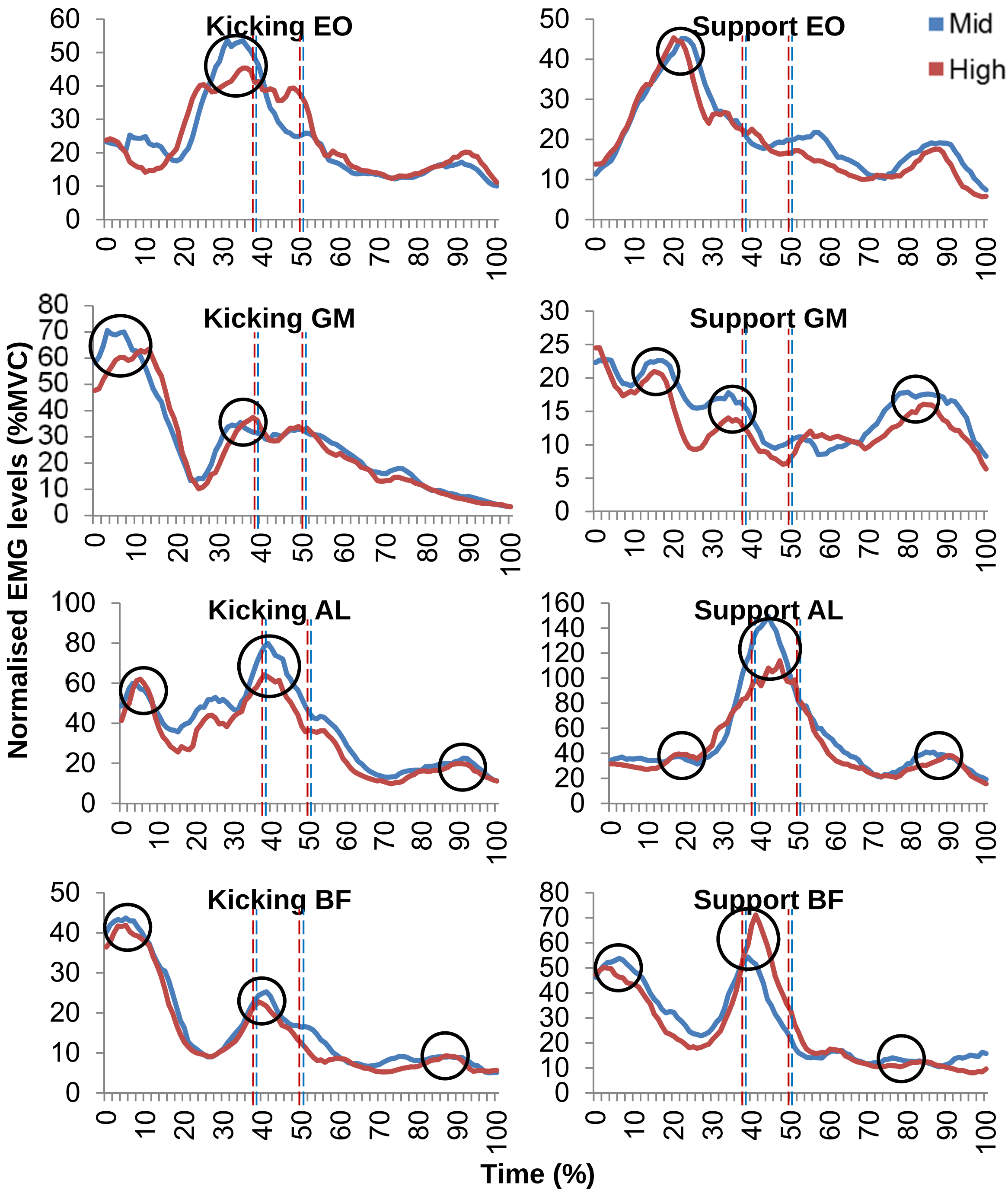

Figure 8 Patterns of activation of the kicking and support leg external obliques (EO), gluteus maximus (GM), adductor longus (AL) and biceps femoris (BF) EMG levels between mid- and high-section turning kicks and their comparable peaks for the 'injury' subgroup. The left vertical line demonstrates the point of most acute knee angle, and the right line, the point of impact.

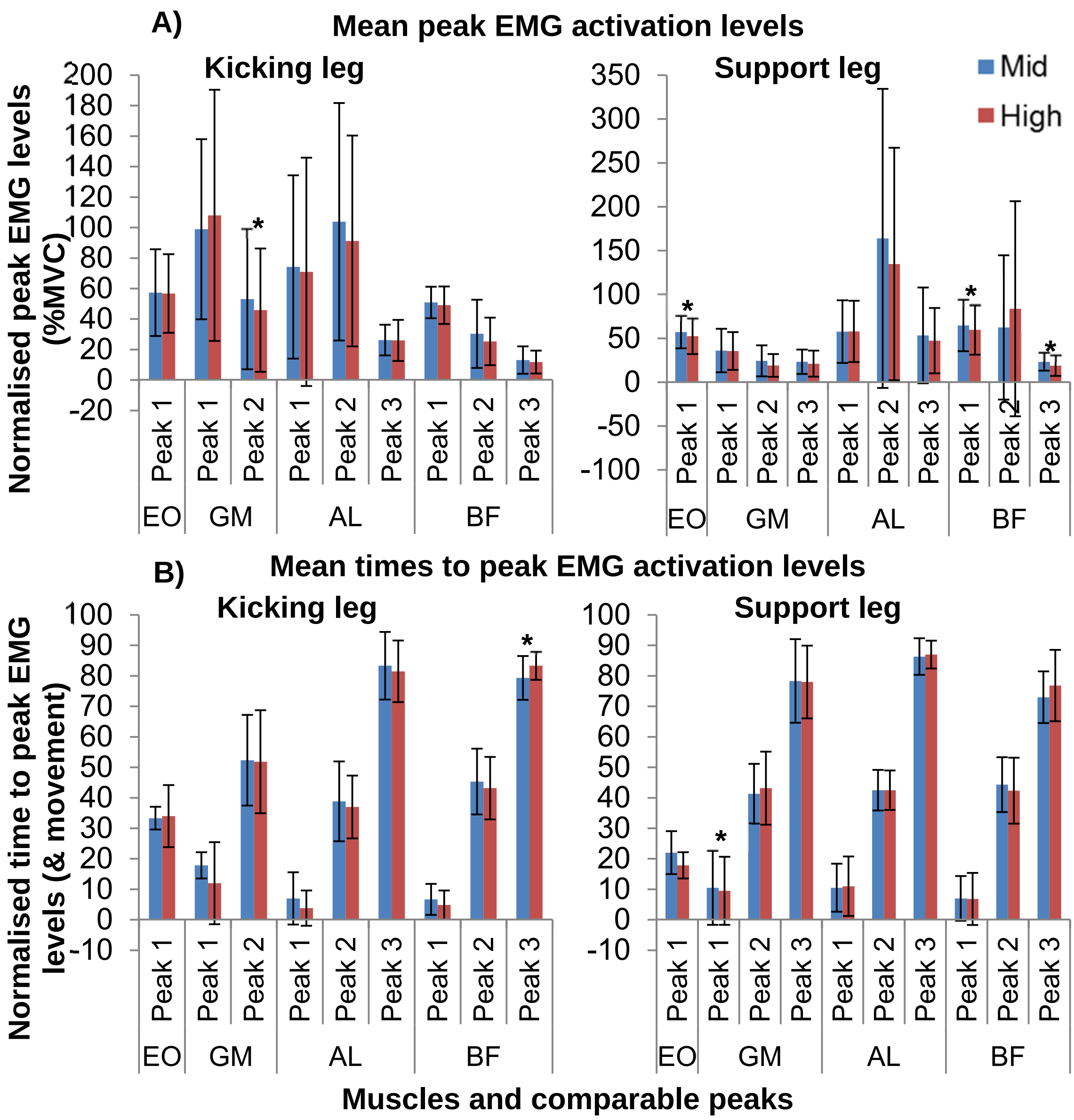

Figure 9 Mean peak EMG activity levels (A) and timings (B) in relation to Figure 8 for the external obliques (EO), gluteus maximus (GM), adductor longus (AL) and biceps femoris (BF) EMG levels between mid- and high-section turning kicks for the ‘injury’ subgroup (* $p < 0.05$, ** $p < 0.01$).

9.3.3. ‘No injury’ subgroup peak EMG levels

No significant differences were found in the peak EMG levels between mid- and high-section turning kicks within the ‘no injury’ subgroup (Figure 11A). Inter-participant CV values were high, ranging from 30.43 % to 119.58 %.

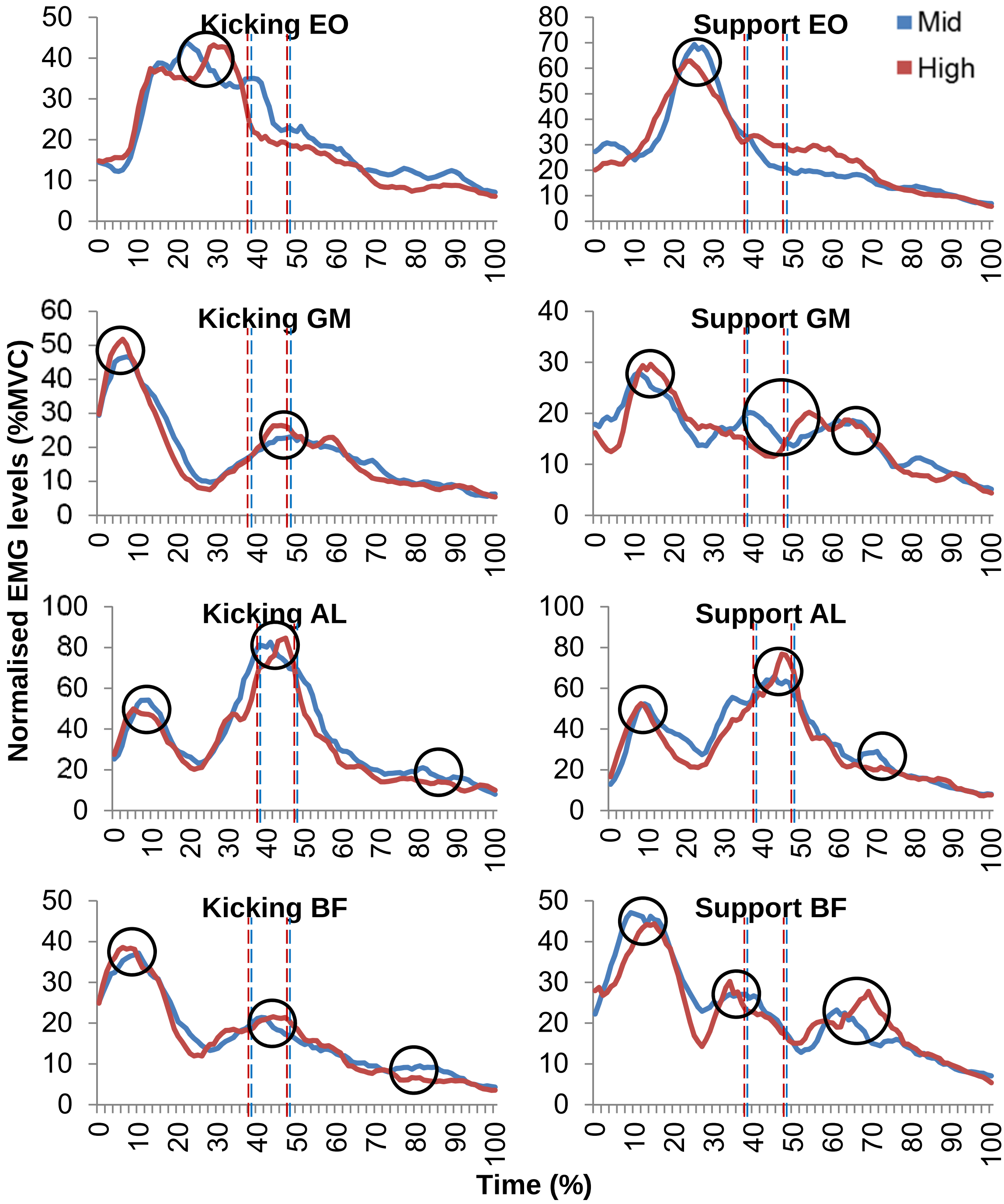

Figure 10 Patterns of activation of the kicking and support leg external obliques (EO), gluteus maximus (GM), adductor longus (AL) and biceps femoris (BF) EMG levels between mid- and high-section turning kicks and their comparable peaks for the 'no injury' subgroup. The left vertical line demonstrates the point of most acute knee angle, and the right line, the point of impact.

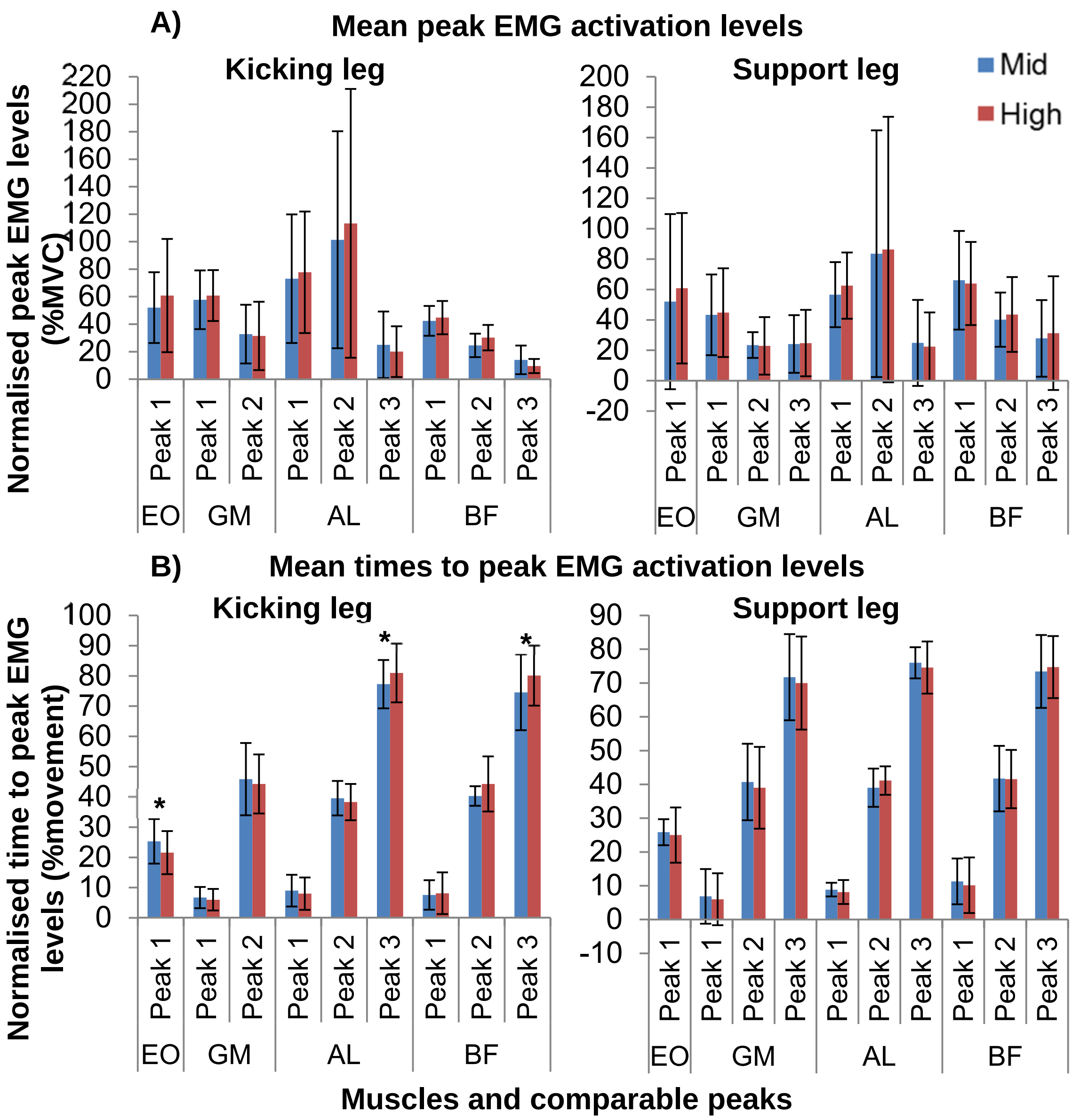

Figure 11 Mean peak EMG activity levels (A) and timings (B) in relation to Figure 10 for the external obliques (EO), gluteus maximus (GM), adductor longus (AL) and biceps femoris (BF) EMG levels between mid- and high-section turning kicks for the 'no injury' subgroup (* $p < 0.05$, ** $p < 0.01$).

A paired sampled *t*-test showed mid-section kicks to exhibit a slower time to kicking leg EO peak EMG activity (52.01 ± 25.75 %MVC at 25.29 ± 7.36 %movement) than in high-section turning kicks (60.83 ± 41.20 at 21.57 ± 7.13 %movement) ($t = 3.07$; d.f. 6; $p < 0.05$; large effect size), thus supporting null hypothesis 2 (Figure 11B).

However, for the final peak in the recovery phase activity occurred later in high-section kicks for the kicking leg BF (9.57 ± 5.15 %MVC at 80.14 ± 9.97 %movement) compared to mid-section turning kicks (14.06 ± 10.40 %MVC at 74.57 ± 12.51 %movement) (t = -2.76; d.f. 6; $p < 0.05$; large effect size). Likewise for the kicking leg AL (high: 20.02 ± 18.41 %MVC at 81.00 ± 9.71 %movement; mid: 24.98 ± 24.20 %MVC at 77.29 ± 7.99 %movement) (t = -1.91; d.f. 6; $p < 0.05$; large effect size). Inter-participant CV values were generally high, ranging from 6.08 % to 128.02 %.

Chapter 4

10. Discussion

This study aimed to compare the kick durations, and EMG levels, timings and patterns of selected lumbopelvis and hip region musculature between mid- and high-section Taekwondo turning kicks. Additionally, these variables were assessed within an ‘injury’ subgroup with a lumbopelvic region injury history, and a ‘no injury’ subgroup.

10.1. EMG pattern analysis

Effective turning kicks are fast, powerful and accurate. They require great segmental coordination. Kicking has been described as a throw-like movement whereby the proximal segment is initiated first with the distal segment lagging. Energy is then transferred from the proximal segment as it decelerates causing rapid acceleration of the distal segment (Dunn & Putnam, 1987; Falco et al., 2009; Katis & Kellis, 2010; Kim et al., 2011; Lees, 2002; Lees & Nolan, 1998; Lees, Asai, Anderson, Nunome, & Sterzing, 2010; Pearson, 1997; Putnam, 1983; Sørensen et al., 1996).

Similar to the present study, Quinzi, Camomill, Felici, Di Mario, and Sbriccoli (2013) found the loading phase to exhibit the greatest EMG levels for the leg GM and BF. In this study this was also evident for the kicking leg EO and support leg EO, GM and BF. Hip musculature is crucial role in movement generation (Quinzi et al., 2013). Effective movement generation is a prerequisite of the quality of the remaining action. Kim et al. (2011) demonstrated hip hyperextension at movement initiation of the turning kick, possibly controlled by the kicking leg GM which peaked just after movement initiation (4 %movement). This would elicit a stretch on the hip flexors, evidenced by the simultaneous peak in kicking leg AL activity, with hip flexion has a secondary action. Early proximal utilisation of the SSC could have enhanced proximal-to-distal energy transfer and increased the work done by the succeeding AL concentric contraction as the hip was abducted and flexed towards impact (Hamilton, Weimar, & Luttgens, 2008).

Greatest kicking leg BF was observed around movement initiation and reduced as the knee flexed. Orchard et al., (1999) demonstrated a subsequent increase in quadriceps activity within this phase of the drop punt soccer kick to control rapid knee flexion. Just prior to the kicking phase, kicking leg BF activity increased as the knee reached maximum flexion; potentially responsible for counteracting excessive quadriceps activity (Katis et al., 2013). Simultaneously, kicking leg EO activity peaked as hip abduction may have climaxed. At the start of the kicking phase kicking leg AL peaked to maintain and stabilising hip abduction (Nunome, Asai, Ikegami, & Sakarai, 2002). Its activity then rapidly decreased allowing forward and lateral acceleration of the thigh, after which kicking leg BF activity decreased allowing fast knee extension towards the target enhanced by the stretch-reflex contraction of the quadriceps. These kinematic and kinetic assumptions are supported by previous kicking research (Dörge et al., 1999; Kellis & Katis, 2007; Orchard et al., 1999; Scurr et al., 2011).

Greater activation of the support leg EO, AL and BF were observed compared to the kicking leg. The support leg EO acts to side bend the torso and collaterally rotate the spine (Calais-Germain, 1999), perhaps aligning the body and providing a stable structure from which to kick. Support leg AL activity peaked in the kicking phase as hip abduction climaxed (Kim et al., 2011). The high velocity movement into this extreme position may have resulted in a rapid adductor stretch-reflex contraction (Hamilton et al., 2008). The support leg remained extended during the kick, potentially resulting in similar response from the support leg BF within the kicking phase. Support leg GM activity fluctuated throughout acting to stabilise.

10.2. Whole group mean and peak EMG activity

Greater overall mean and peak EMG activity was observed during mid- compared to high-section turning kicks. Significant differences were observed for the kicking leg GM and AL mean EMG levels and kicking GM peak EMG level. This accepted null hypothesis 1. However, albeit insignificant, high-section kicks exhibited greater peak EMG values for the kicking leg EO, GM and AL, and support leg GM and AL in the loading phase and for the kicking leg AL and BF, and support leg BF in the kicking phase.

The muscles investigated and the support leg's inclusion in the present study was fairly novel compared to previous martial arts research. Luk and Hong (2000) found significantly greater activity of the sartorius, tensor fascia latae, vastus lateralis, and gastrocnemius in high-section compared to mid-section turning kicks ($p < 0.05$) perhaps because of the greater ROM required of high-section kicks increasing the stretch on these muscles (Kim et al., 2010). However, high kicking speed and force are significant parameters in kicking performance (Luk & Hong, 2000). Like the present study, Hong et al. (2000) reported shorter kicking duration for mid- (0.80 ± 0.09 s) over high-section turning kicks (0.90 ± 0.09 s). Theoretically, this could be attributed to the greater EMG activity through more rapid muscle loading within the loading phase and start of the kicking phase. However, Li et al. (2005) reported greater kicking velocity of the high- over the mid- section turning kick, thus suggesting that kick velocity and duration may not be linked; casting doubt on this assumption.

10.3. 'Injury' and 'no injury' subgroup mean and peak EMG levels

Within the 'injury' subgroup, during mid-section kicks greater peak activity was observed throughout compared to high-section turning kicks. This difference was significant for the kicking leg GM and support leg EO and BF in the loading phase. Although statistically insignificant, the largest observable difference was for the kicking and support leg AL in the kicking phase. Interestingly, in the ‘no injury’ subgroup the opposite was observed but with no significance. This suggests that the effect of target height on EMG activity is most influential in those with lumbopelvic region and related injury history. Wallden and Walters (2005) found greater lumbopelvic dysfunction in professional soccer players with a history of recurrent hamstring strain. Therefore, these participants could be at greater risk of injury reoccurrence particularly when performing mid-section turning kicks for reasons explained previously.

No statistical comparisons were made between the two subgroups however; the coactivation of the support leg GM and AL was less in the ‘injury’ than the ‘no injury’ subgroup, particularly in mid-section turning kicks. Morrissey et al. (2012) found significant reductions in the ratio of gluteus medius to AL muscle activity in participants with chronic groin strain during standing hip flexion. Over-activity of the AL could be associated with groin injury.

Furthermore, ‘injury’ subgroup peak activity, particularly kicking leg GM and BF in the loading phase and the support leg AL in the kicking phase, were generally greater and occurred sooner than the ‘no injury’ subgroup. The ‘no injury’ subgroup experienced peak activity close to impact. In the ‘injury’ subgroup the activity of the kicking leg AL and BF and support leg AL peaked just after the point of greatest knee flexion after which it decreased. Muscle pre-activation prior to and during an impact increases joint stiffness, which is an important soft-tissue injury prevention mechanism (Besier, Lloyd, & Ackland, 2003). Stretch-reflex contractions could enhance this mechanism through greater muscle spindle preparation for detecting, responding, and modulating changes in muscle fibre length in order to regain equilibrium post-impact (Hamilton et al., 2008; McArdle, Katch, & Katch, 2007). Perhaps the greater execution time for high-section turning kicks could hold explanation their lower EMG levels with longer to adapt before impact. However, this is difficult to conclude without velocity / acceleration data.

10.4. Main limitations and future recommendations

Importantly, the majority of inter-participant CVs were greater than 80.00 % and some over 100.00 %. The maximum biomechanically acceptable CV is 10.00 % (Winter, 1991). This demonstrates poor inter-participant reliability of the EMG signals of the muscles of interest during the turning kick. The appropriateness of CV for waveform data analysis has been queried (Aggeloussi et al., 2007; Duhamel et al., 2004; Preatoni et al., 2013). Intraclass correlation coefficients (ICC) and coefficient of multiple correlation (CRC) have been suggested as more appropriate (Duhamel et al., 2004). ICC is required greater than 0.80 for discrete measure and 0.90 for waveforms. However, during the Taekwondo chop kick Aggeloussis et al. (2007) found that ICC ranged between 0.42 to 0.91 for the rectus femoris, BF, gastrocnemius, and tibialis anterior, and CMC did not exceed 0.72. Low inter-participant repeatability could be associated mostly to the type, magnitude, velocity and synchronisation of the muscle contractions (Winter, 2009), the magnitude, number and the firing rate of the motor neurones beneath the electrodes (Araujo, Duartem, & Amadio 2000; Konrad, 2005), and individual kicking style. Therefore, the results of the study should be treated with caution.

Furthermore, the number of participants and / or the number of trials may have affected the CV. Group homogeneity may hold some explanation. The sample contained an unequal number of male and female participants, weight divisions varied from -54 kg to -87 kg, and although all participants were healthy at the time of testing, some had a history of lumbopelvic related injuries. The latter may affect the validity of the results and the variability particularly when investigating the whole group. However, even within the 'injury' subgroup, homogeneity was compromised by a variety of past gluteal, groin and hamstring injuries on either the kicking or support leg. Future studies should recruit a greater number of participants and / or perform a greater number of trials to reduce variability.

Thirdly, some participants produced EMG levels of 300 %MVC during the kicks. Manual muscle testing was performed to ensure placement accuracy, suggesting that the isometric MVCs were inaccurate. Given the impact and highly dynamic nature of turning kicks other MVC methods may have been more appropriate. Burden (2010) recommended arbitrary angle isometric MVCs obtained from a mid-range joint angle, or specific maximal dynamic voluntary contractions with the same muscle action and joint angle as the task. Additionally, earlier visual inspections of the data and examinations of EMG variability should be performed prior to EMG investigations on high velocity, dynamic actions, especially involving impacts (Aggeloussis et al., 2007).

Finally, few muscle groups were assessed. A more in-depth study on the coactivation of agonist and antagonist muscles would enhance the understanding of how the turning kick is produced and controlled, the differences between mid- and high-section turning kicks, and give more reliable insights into lumbopelvic related injury provoking activity. Furthermore, the inclusion kinematic analyses would supplement data interpretation.

10.5. Conclusions

Greater EMG activity was produced during mid- compared to high-section turning kicks, and significantly so for the mean EMG levels of the kicking leg GM and AL and kicking phase peak activation of the kicking leg GM. Furthermore, within the ‘injury’ subgroup significantly greater loading phase support leg BF activity was observed during mid-section compared to high-section turning kicks. This may suggest a greater support leg hamstring injury risk during movement initiation of mid-section turning kicks, particularly in those with lumbopelvic region related injury history. Times to peak EMG level results were inconclusive, however, the significantly shorter duration of the mid-section kicks could aid to explain this outcome through greater kicking velocities inducing more rapid muscle loading. The greater ROM required of high-section kicks appeared significantly non-influential on the EMG activity of the selected muscles. However, within the ‘injury’ subgroup, albeit statistically insignificant, greater kicking phase support leg BF activity was observed in high- compared to mid-section turning kicks, thus suggesting it may be under strain as a result of a stretch. As this was apparent within the whole group, it may give reason for the high hamstring injury rates in Taekwondo. Additionally, within the ‘injury’ subgroup the support leg appeared vulnerable to injury reoccurrence due to high loading phase BF activity, kicking phase AL activity, and poor kicking phase coactivation of the GM and AL. Unfortunately, high CV (< 0.80) suggests poor EMG data repeatability. Further research is needed to provide more valid conclusions and to suggest practical implications.

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12. Appendices

Appendix 1 – Ethical approval

This can be found on disk 1. It contains:

Appendix 1A	The accepted ethical approval application form.
Appendix 1B	The appendices for the accepted ethical approval form.
Appendix 1C	The approval letter from the Faculty of Research Ethics Committee.

Appendix 2 – Participant details

Appendix 2A Participant details and anthropometric measurements.

Participant	Sex[1]	Age (years)	Mass (kg)	Stature (m)	Dominant leg
1	M	21	67.50	1.76	Right
2	M	20	76.80	1.80	Right
3	M	26	68.00	1.82	Right
4	M	17	71.60	1.80	Right
5	M	21	90.00	1.87	Right
6	F	21	74.00	1.80	Right
7	M	18	61.60	1.67	Left
8	F	20	59.60	1.71	Left
9	M	17	69.00	1.77	Left
10	F	20	75.60	1.78	Right
11	M	23	70.00	1.77	Left
12	M	25	77.70	1.80	Left
13	M	26	86.00	1.86	Left

Notes

[1] M = Male, F= Female

Appendix 2B Participant lumbopelvic region related injury history 8 months prior to testing and subsequent grouping.

Participant	**Groin injury**	**Hamstring injury**	**Glute injury**	**Injury subgroup**
1	No	No	No	No
2	No	No	No	No
3	No	No	No	No
4	No	No	No	No
5	No	Yes	No	Yes
6	Yes	No	Yes	Yes
7	No	No	No	No
8	No	Yes	No	Yes
9	Yes	No	Yes	Yes
10	Yes	No	No	Yes
11	No	No	No	No
12	No	Yes	No	Yes
13	No	No	No	No

Appendix 3 – Raw MyoResearch EMG data

Appendix 3A, 3B can be found on disk 1. It contains subfolder including:

Appendix 3A	This contains the raw MyoResearch files for individual participants including MVCs, all mid- and high-section turning kick EMG files and their associated video files.
Appendix 3B	This contains folders for each participant in which their originally exported text files from MyoResearch are found. It includes each trial, MVC and baseline reading.

Appendix 3C – Isometric MVC (uV) values for each participant.

	Participant number												
Muscle	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
RtEO	375	428	1013	153	1007	395	304	231	377	125	998	592	566
LtEO	332	495	656	302	919	225	321	368	541	86.1	378	582	691
RtGM	374	229	454	247	264	551	190	202	542	88.5	341	373	396
LtGM	354	597	299	243	611	452	180	175	324	91.5	483	567	504
RtAL	575	298	960	471	440	426	1169	524	630	108	545	690	668
LtAL	859	165	817	1452	551	582	1018	959	946	171	861	712	1012
RtBF	1424	952	843	804	429	702	761	646	582	335	523	732	360
LtBF	853	1348	802	688	333	620	795	428	759	507	797	719	442

Appendix 4 – Statistical analyses

This can be found on disk 1. It contains:

Appendix 4A	SPSS input and output files for each variable compared and within each group. It also contains Excel files of the paired sampled *t*-tests showing the one-tailed significance calculation.
Appendix 4B	An Excel file reporting the *p* values, coefficient of variations and effect sizes for all comparisons within all groups disregarding the kick duration comparison which is reported within the text.

Appendix 5 – Results files

This can be found on disk 1. It contains:

Appendix 5A	This contains raw Excel files for each participant amalgamating the data from the exported text files from MyoResearch, and demonstrating the time-normalised data for all trials. Each trail is in a separate tab.
Appendix 5B	An Excel spread sheet in which mid- and high-section turning kick data were normalised to %MVC for each participant and averaged across participants for the whole, ‘injury’ and ‘no injury’ groups to produce the data used for statistical analyses and data visualisation. It also includes coefficient of variation calculations. Each muscle is in a separate tab.

Disk 1